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Properties of Rice Husk Ash Concrete Containing Nano-SiO_2

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ABSTRACT

As the burning process strongly affects the pozzolanic activity of produced RHA, in some cases RHA concretes suffer low initial strength. Integrating nano-SiO_2 with RHA in concrete seems to be beneficial to overcome this problem. Hence in this paper, an effort was made to investigate the effect of nano-SiO_2 in improving the properties of RHA concrete. Accordingly 3 % nano-SiO_2 was incorporated into RHA concrete. The amount of RHA was 20%, (by weight of cement) which is an acceptable range and is most often used. The compressive and flexural strength tests were carried out at 7 and 28 days. The drying shrinkage of specimens was measured up to the age of 42 days. The water absorption test was also carried out at 28 days. According to the results, compressive and flexural strength of RHA concrete improved with the incorporation of nano-SiO_2. Effect of nano-SiO_2 on water absorption of RHA concrete was significant.

INTRODUCTION

Undoubtedly, nano-technology can be considered as one of the most significant breakthroughs in the scene of science. The enormity of nano-technology lies in this fact that it has changed our view point toward the material world. Recently nano-technology has gained increasing scientific interest due to the new potentials of using nano-scale particles. The nano-size particles show unique physical and chemical properties (different from those of the conventional materials) as a result of their ultra-fine size [Sobolev et al. 2006]. The use of nano-particles can improve the function and properties of many types of materials. Reinforced plastics, fire-retardant materials, protective films or cloths, and high-quality coatings are among the many diverse applications of nano-composites [Aiu 2006]. There is this prediction that the construction material fields can substantially progress utilizing nano-technology developments. Application of nano-materials into the production of cement and concrete can lead to improvements in civil infrastructure, because the mechanical strength and life of concrete structures are determined by the micro-structure and by the mass transfer in nano-scale [Hanehara et al. 2001].

Nano-particles of silicon dioxide were found to be very effective to cement-based composites with improved workability, durability and strength. The pozzolanic activity of nano-SiO_2 is more obvious than that of silica fume. As the rate of pozzolanic reaction is proportional to the amount of surface available for reaction and owing to the high specific surface of nano-SiO_2 particles, they possess high pozzolanic activity [Qing et al. 2007]. Studies have shown that incorporation of nano-SiO_2 into cement based materials improved their physical and mechanical properties significantly [Shih et al. 2006; Jo et al. 2007]. Filling the voids of CSH gel structure and generating homogeneous distribution of the hydrated products beside reduction the quantity of big and porous portlandite macro crystals are mainly responsible for mechanical strength improvement caused by nano-SiO_2 [Dotto et al. 2006]. Furthermore, it has been found that when the small particles of nano-SiO_2 uniformly disperse in the paste due to their high activity generate a large number of the nucleation sites for the precipitation of the hydrated products accelerating cement hydration[Li et al. 2004].

According to the FAO statistical database, more than 650 million tones of rice paddy has been produced in 2008 all around the globe. As one-fifth of paddy is husk, total production of rice husk is 200 million tones [FAO Statistical Database, 2008]. Because rice husk in its raw form has a limited application, in the majority of rice producing countries (mostly under developed countries) much of the husk produced from the processing of rice is burnt or dumped as a waste which creates a serious environmental problem. Despite raw rice husk, rice husk ash due to high amounts of SiO_2 is useful to many industrial applications. One main use of RHA has been identified as a pozzolan in cement industry [Nair et al. 2007]. It has been demonstrated that rice husk ash (RHA) can be added to concrete mixtures to substitute the more expensive Portland cement to lower the construction cost. Also it has been found that concrete made with Portland cement containing RHA has a higher sulfate and acid resistance and lower chloride permeability [Yu et al. 1999]. As the burning process strongly affects the pozzolanic activity of produced RHA, in some cases RHA concretes suffer low initial strength.

Integrating nano-SiO_2 with RHA in concrete seems to be beneficial to overcome this problem. Some similar efforts have been carried out on cement composites containing sludge ash and fly ash. Gengig Li [2004] showed that incorporating nano particles to high-volume fly ash concrete can significantly increase the initial pozzolanic activity of fly ash. He also concluded that nano-SiO_2 can enhance the short-term and long-term strength of high volume high strength concrete. Lin [et al. 2007] reported that nano-SiO_2 particles could potentially improve the negative influences caused by sludge/fly ash on the early strength of mortar. Moreover, it has been found that combining two or more components with different particles size distribution can increase the packing density effectively. Adding a fine powder to a coarse one which is a conventional technique in ceramic production is based on this fact [Kaufmann et al. 2004]. Accordingly in this study, nano-SiO_2 particles were integrated with RHA in concrete and different properties of the products including compressive and flexural strength, shrinkage and water absorption, were determined.

EXPERIMENTAL PROCEDURE

Material properties

In this study, ordinary Portland cement type I, standard graded sand, rice husk ash, nano-SiO_2 particles and tap water were used. RHA used in this experiment contained 92.1% SiO_2 with average diameter of 15.83 µm. The chemical compositions of RHA and cement were analyzed using an X-ray microprobe analyzer (Table 1). In order to achieve desire fluidity and better dispersion of nano particles, a polycarboxylate ether based superplastisizer was incorporated into all mixes. The content of superplastisizer was adjusted for each mixture to keep constant the fluidity of concretes. Coarse aggregate was crushed rock with a maximum size of 20 mm and a specific gravity of 2.70. The fine aggregate was natural sand with a fineness modulus of 2.35 and a specific gravity of 2.50. Basic material properties of nano-SiO_2 are given in Table 2.

Table 1. Chemical compositions of cement and rice husk ash

Item	Chemical Compositions (%)						
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	L.O.I
Cement	21	4.6	3.2	64.5	2	2.9	1.5
RHA	92.1	0.41	0.21	0.41	0.45	-	-

Table 2. Basic Material Properties of Nano-SiO_2 (in liquid form)

Composition (mass %)	SiO_2 (30%), H_2O (70%)
Diameter (nm)	50
Density (gr/cm^3)	1.03
PH value	10

Test method

In order to achieve desire properties, it is essential to disperse nano-SiO_2 particles uniformly. Accordingly mixing was carried out in a rotary mixer as follows:

1. The polycarboxylate superplasticizer was dissolved in water, and then the nano-SiO_2 was added and stirred at a high speed for 2 min.
2. The cement, fine aggregates, coarse aggregates and RHA were mixed in a rotary mixer for 30 s.
3. The ready-mixed liquid including water, superplasticizer and nano-SiO_2 was poured into the rotary mixer slowly. The concrete mixture was mixed for another 1.5 min.
4. After mixing, the slump of the concrete mixtures was measured.

The well-mixed concrete mixture was cast in cubes of 100 mm for the compressive strength and water absorption tests and 100×100×300 mm molds for flexural and shrinkage tests. The samples were demolded after 24 h and cured in water at 23±2 ℃ until testing. The testing age was after 7, 28, 60 and 90 days.

Mix Proportion

Initially, in order to find out the optimum mixing proportion of nano-SiO_2 and RHA, a series of standard mortars according to ASTM C 305 were made and compressive strength of the products at 7 and 28 days were determined following the procedure of ASTM C 109. Details of mix proportions for mortars and compressive strength results are given in Table 3. Based on the obtained results, mixture RHN3 was chosen as the optimum mortar. Accordingly, 3 % nano-SiO_2 was incorporated with 20% RHA for the rest of investigation in concrete scale. Details of the mix proportions for concretes are given in Table 4. The amount of RHA replacement in all concretes was 20% by weight of cement which is an acceptable range and is most often used [Sadrmomtazi et al, 2008]. The water/binder ratio for all concretes was 0.5 where the binder weight is the total weight of cement, RHA and nano-SiO_2.

Table 3. Mix Proportion and Compressive Strength of Standard Mortars

No	*Sand/Binder*	*Water/Binder*	% Content (by weight)			Compressive Strength ((MPa)	
			PC	RHA	NS	7 days	28 days
1	2.75	0.5	80	20	0	27.1	37.6
2	2.75	0.5	79	20	1	30.1	41.9
3	2.75	0.5	77	20	3	38	47.2
4	2.75	0.5	75	20	5	39	47.8

Table. 4. Mix Proportions of Concretes (Kg/m^3)

No	Binder				Aggregate		W/B[a]	Superplasticizer[b]
	PC	RHA	NS	Total	Fine	Coarse		
CO	480	-	-	480	810	1030	0.35	0.2
RHC	384	96	-	480	810	1030	0.35	1.1
RHNC	369.6	96	14.4	480	810	1030	0.35	1.5

[a] Water/binder (i.e., PC plus additional materials) ratio.
[b] Dosages given as percent of total binder content by mass.

EXPERIMENTAL RESULTS AND DISCUSSION

Compressive and flexural strength

The compressive and flexural strength test results are shown in Figs. 1 and 2. It can be seen that the compressive strength of RHA concrete is lower than that of control concrete. Adding nano-SiO_2 increased the compressive strength of RHA concrete. Similar behavior can be observed for flexural strength. Generally, two fundamental mechanisms can be deduced for strength enhancement of RHA concrete by nano-SiO_2: first, strength enhancement by matrix densification and paste-aggregate interfacial zone refinement. Evidence from numerous

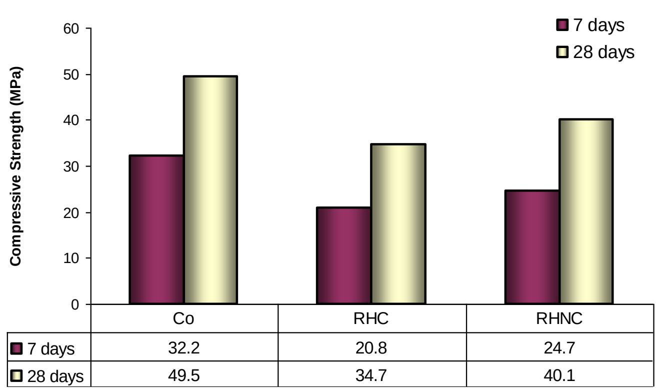
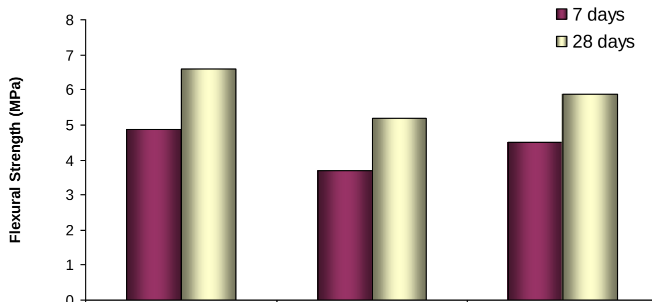


Fig. 1. Compressive Strength of Different Concretes



	Co	RHC	RHNC
7 days	4.87	3.68	4.49
28 days	6.58	5.19	5.89

Fig. 2. Flexural Strength of Different Concretes

studies has shown that the microstructure of transition zone between aggregates and cement paste strongly influences the strength and durability of concrete [Li et al. 2001]. The presence of nano-SiO_2 particles reduces the wall effect in transition zone between the paste and the aggregates and strengthens this weaker zone due to the higher bond between those two [Isaia et al. 2003]. Strength enhancement by pozzolanic reactions is the second mechanism. Pozzolanic materials are generally able to combine with the hydrated calcium hydroxide ($Ca(OH)_2$) which has a low cementing property forming the hydrated calcium silicate (C–S–H), which is the principal responsible for the strength of hydrated cement pastes [Rao 2003]. Previous studies have showed that the nano-SiO_2 particles can significantly increase the pozzolanic activity of other pozzolans which have low initial activity. It can be concluded that nano-SiO_2 increased the initial pozzolanic activity of RHA. Furthermore, it was proved that the cement paste characteristics for instance mechanical properties and fluid permeability strongly depend on the nanostructure features especially nano porosity [Boch et al. 2004]. Porosity widely depends on the chemical composition of the raw materials, their hydration processes and the packing properties of the different components. It seems that integrating nano-SiO_2 particles with RHA in concrete improved the packing density and reduced the porosity of cement matrix which plays a vital role in mechanical strength.

Drying shrinkage

Shrinkage is a common phenomenon generally encountered in almost every cementitious product due to contraction of total mass upon loss of moisture. It is sometimes accompanied by development of cracks especially in such members whose surface area to volume ratio is large [Rao 2001]. Regarding to the importance of volume changes caused by shrinkage, this section is devoted to study the influence of nano-SiO_2 on the drying shrinkage of concrete containing RHA. To this end, prismatic specimens of 100×100×300 mm were prepared. The first measurement was taken using a length comparator with a precision of 2μm after 24 h of mixing, while the rest of measurements were taken at different ages of 3, 7, 14, 21, 28, 35, 42 days. The specimens were cured in the laboratory environment. The average temperature in the laboratory was $26±3^{℃}$. The shrinkage behavior of different concretes is presented in Fig. 3. From this figure, we can see that RHA concrete (RH) showed higher drying shrinkage as compared with control concrete (Co). The drying shrinkage of RHN is similar to that of control concrete. Results indicate that the nano-SiO_2 particles could contribute positively to moderate the length change caused by the drying shrinkage.

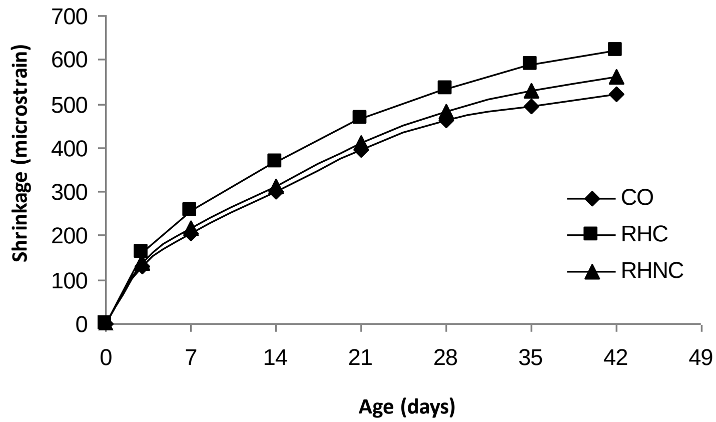


Fig. 3. Shrinkage Behavior of Different Concretes

Water absorption

Water absorption test was carried out at 28 days of curing on cubes of 100 mm as follows: Saturated surface dry specimens were kept in an oven at 110$^{\circ}C$ for 72 h. After measuring the initial weight, specimens were immersed in water for 72 h. Then the final weight was measured and the absorption was reported to assess the concrete permeability. For every absorption value, two specimens were tested and averaged. The water absorption test results are given in Fig. 4. We can see that RHA replacement in concrete increased water absorption value as compared with control specimen. It can be observed that integrating nano-SiO_2 with RHA in concrete (RHNC) resulted in a lower water absorption value. It might be due to increase of packing density of composite because of combining three components (cement, RHA, Nano-SiO_2) with different particles size.

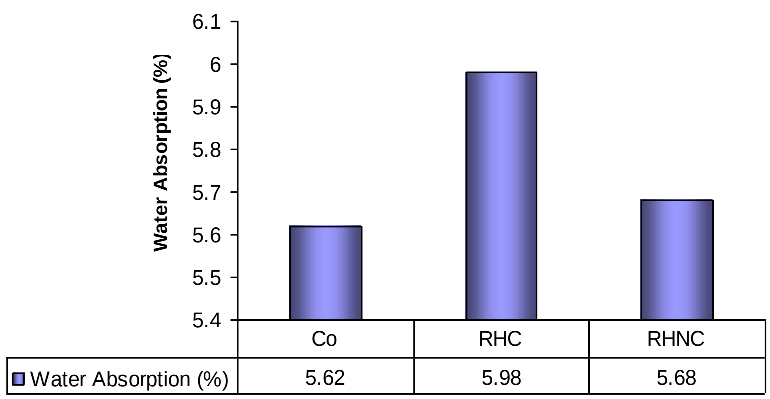


Fig. 4. Water Absorption of Concretes

CONCLUSION

This paper presents a laboratory study on the properties of RHA concrete incorporating nano-SiO_2. On the basis of experimental data, the following observation and conclusion are made:

1. Concrete containing 20% RHA showed lower compressive strength as compared with control concrete. Incorporating 3% nano-SiO_2 into RHA concrete caused an increase in compressive strength of the products. Similar trend was observed in the case of flexural strength.

2. According to the shrinkage test results, the nano-SiO_2 particles could contribute positively to moderate the length change caused by the drying shrinkage. Though the shrinkage values of RHA concrete were higher than that of control concrete, it was significantly decreased by adding nano-SiO_2.

3. The absorption characteristics which indirectly reflect the porosity show that the replacement of cement by RHA in concrete increased the water absorption significantly. The presence of nano SiO_2 particles in concrete containing RHA resulted in a lower absorption value.

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